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Analyzing of the Woven Fabric Geometry on the Bending Rigidity Properties

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Abstract The main content dealt with in this study is analyzing of the bending rigidity of woven fabrics as a function of fabric structure, fabric density (warp and weft spacing) and yarn counts to compare and approve the correspondence results of automatic cyclic bending tester made by Ajeli (Ajeli, Jeddi, Rastgo, & Gorga, 2009) at university of Amirkabir-Tehran with Shirley tester. And also we prepared microscopic pictures from cross section of the samples and achieved the aspect ratio of cross section of yarns in fabric structure (MATLAB software) in order to appropriate analysis of their mechanical behavior during implemented bending forces. For this purpose, five woven fabrics (plain, Twill 1/2, Twill 1/3, Twill 1/4, and Twill 1/5) are fabricated with three different densities (23, 29 and 35 warp per centimeter). The results show that the bending rigidity decreases with increasing of float yarns on both warp and weft directions. Furthermore, the value of bending rigidity on technical front side of the samples is less than technical back sides. Also there is difference between bending rigidity of weft and warp direction. There is a reasonable agreement between the measured values for both techniques.

Keywords Woven Fabric, Fabric Structure, Bending Rigidity, Automatic Cyclic Bending Tester, Fabric Density, Shirley Tester

1. Introduction

Textile industry needs to be brought the texture process to higher technological stage which requires proper evaluating and simulating techniques to predict the future mechanical and physical characteristics of textiles (Ancutienė, Strazdienė, & Nesterova, 2010) (Luible & Magnenat - Thalmann, 2007). Analyzing the mechanical properties can enhance to determine the behavior of the fabrics during clothing exploitation. The mechanical properties of a fabric are depended to their geometry and also related to the formability and mechanical properties of the constituent yarns. Therefore, the study of fabric bending rigidity is very complicated because of the mechanical properties, arrangement and interaction between its constituent yarns (Fatahi & Yazdi, 2010) (Syerko, Comas-Cardona, & Binetruy, 2012). Fabric bending rigidity is one of the most important factors which has affect on handling and comfort of apparel; in 1930, the bending behavior has been explored quite extensively, beginning by Peirce (Peirce, 1930). On the other hand, bending rigidity is one of the most important properties of fabrics and is a key component in deciding fabric handle and drape. It is an important contributor to fabric's formability (Allaoui, Hivet, Wendling, Soulat, & Chatel, 2011), buckling behavior (Dehkordi, Nosraty, Shokrieh, Minak, & Ghelli, 2010), wrinkle-resistance (Merati & Patir, 2011) and crease resistance (Merati & Patir, 2011). Knowledge of bending becomes particularly important when attempting the automation of processes involving out-of-plane manipulation. Abbott, et.al (G. A. V. Abbott, G.M., Gorsberg, P., & Leaf, 1973) (Abbott, N., Coplan, M., & Platt, 1960) proposed that because of the pressures at the crossover points, the yarn in the woven fabric is composed essentially of alternate rigid and flexible sections and it is assumed that the yarn lies in a straight line . Later, Grosberg, et.al (Grosberg, P., 1966) (Kedia., 1966) suggested that the bending behavior of woven fabrics is non-linear and is separated into two components: flexural rigidity and frictional resistance (Grosberg, 1966). It has been difficult to characterize the mechanisms of fabric bending. In 1971 a bending fabric model was proposed by Abbott, et.al (G. A. . Abbott, G.M., Gorsberg, P., & Leaf, 1971). They assumed that fabrics made from a large number of long and thin plates are such that the shear effect during bending can be neglected and therefore investigated the bending of a series of parallel plates. A theoretical analysis was used to obtain the predicted relationship between the applied couple and the curvature of the fabric, which contradicted the earlier work of Abbott in 1960 (Abbott, N., Coplan, M., & Platt, 1960). Grosberg and Abbott (Grosberg, P., & Swani, 1966) discussed the apparatus of Livesey and

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Owen (Livesey, R., & Owen, 1964) that bends the fabric in almost constant curvature. Also the importance of friction during the bending process and note that large errors are present if a linear bending approximation is used (Kedia., 1966). One of the initial models of fabric bending was done by Grosberg and Swani (Grosberg, P., & Swani, 1966) which modeled bending with an initial frictional restraint M_0 that must be first overcome then a linear moment-curvature relationship. The M_0 represents frictional resistance to bending at the yarn intersections. Once this frictional resistance is overcome, the yarns can be bent; hence the linear relationship once the initial resistance is overcome. Leaf et al (Leaf, G.A., Chen, Y., & Chen, 1993) considered a model by using strain energy and Costigliano's theorem and developed a relationship between the flexural rigidity of a plain-woven fabric and the fabric and yarn parameters (Sun & Stylios, 2012).

Ajeli et al. (Ajeli et al., 2009) investigated on the bending rigidity of warp-knitted fabrics as a function of knit structure (underlaps length), density (wale and course spacing) and yarn bending properties. The bending rigidity of the fabrics is measured by means of a Kawabata evaluation system and a prototype automatic cyclic bending tester. Results showed that the bending rigidity increases for the fabrics with a higher density and underlaps length of the front and back guide bars.

Hence, the main aim of the present study is to clarify, in detail, the consequences of bending behavior of woven fabrics by consideration of increasing float yarns at fabric structure, fabric density (warp and weft spacing) and yarn counts by means of automatic cyclic bending tester made by Ajeli (Ajeli et al., 2009) and the validity of our approaches as matter of variation trend with the experimental data evaluated by Shirley tester.

2. Experimental Analysis

2.1. Preparing the Samples

The research presented in this paper covers the practical verification of the monogram's utility, as well as includes an analysis of the changes in the structure parameters at the moment of bending the three types of woven polyester continuous filament fabrics designed to show that difference between them which are caused by different float yarns inside of fabrics. All of the fabrics used the same polyester continuous filament warp of 3.5 tex. The weft differed in its linear density (7.8 tex, 11.5 tex, 16.7tex). The five forms of woven fabrics (plain, Twill 1/2, Twill 1/3, Twill 1/4, Twill 1/5) weaved. The density of yarns per centimeter considered constantly 60 $\frac{\text{Ends}}{\text{cm}}$ for warp yarns and 23$\frac{\text{Ends}}{\text{cm}}$, 29$\frac{\text{Ends}}{\text{cm}}$ and 35 $\frac{\text{Ends}}{\text{cm}}$ for weft yarns.

2.2. Shirley Tester

In most cases, authors who deal with the bending effect of textiles take advantage of Peirce's theory as presented in the classic work that implemented by Pierce (Peirce, 1930) which contains the theoretical fundamentals on which most of today's methods for the static measurement of bending rigidity are based. Bending rigidity of fabrics in warp and weft directions and also on technical back and front side of samples were measured by use of two different instruments, Shirley evaluation system (based on Pierce method) as can be seen in Figure 1 and an automatic cyclic bending tester (based on Livesey and Owen method). The amount of bending moment of the sample is determined and the relationship between the bending moment and the length of curvature is obtained as follow.

$$B = (\frac{L}{2})^3 q \quad (1)$$

Where L is length of bending and q is gr/cm^2. The sample's length and width were 6 and 1 inch respectively.

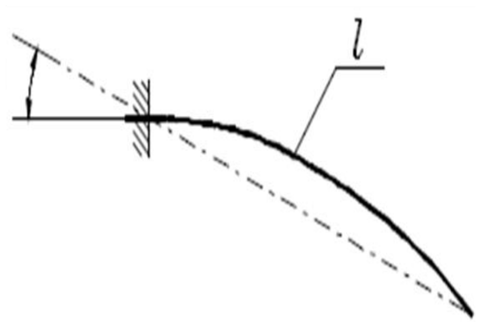
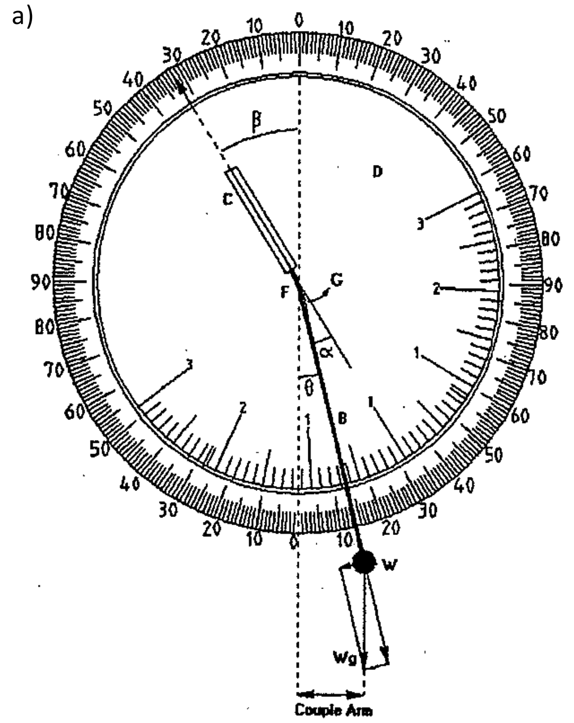


Figure 1. principal of shirley tester (Livesey, R., & Owen, 1964)

2.3. Automatic Cyclic Bending Tester

a)



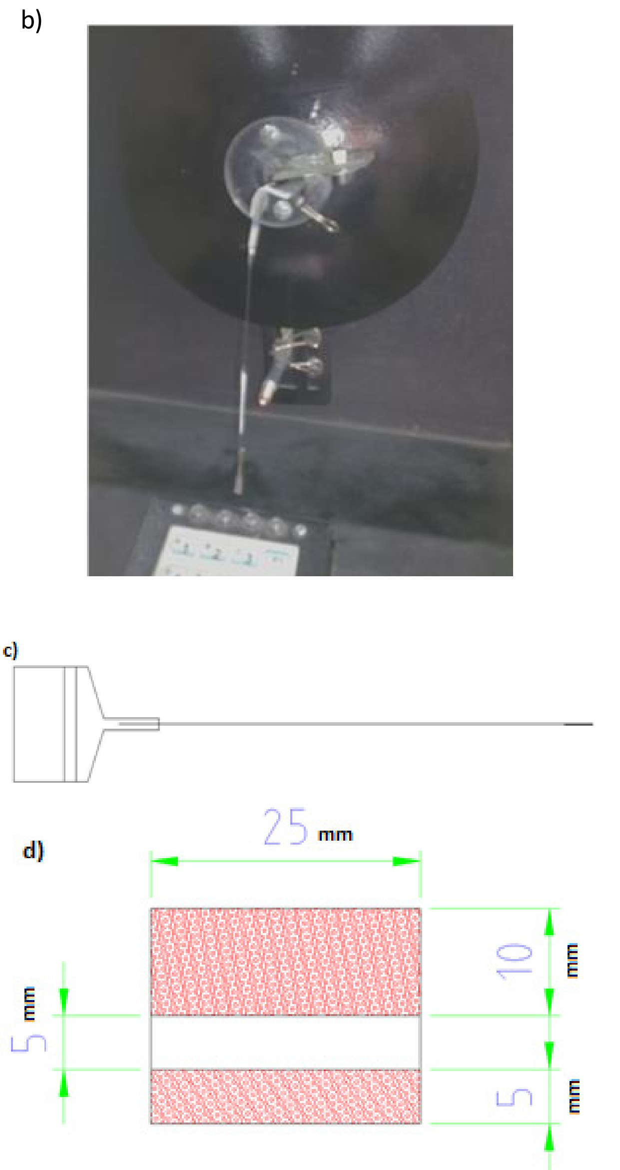


Figure 2. a) cyclic bending tester made by Liversey et al (Livesey, R., & Owen, 1964) b) automatic cyclic bending tester made by Ajeli (Ajeli et al., 2009) c) the specimen pattern d) sample's dimension

The second test method, automatic cyclic bending tester, works based on Livesey and Owen's apparatus (Livesey, R., & Owen, 1964). In this instrument, the bending moment of specimen is gradually changed and the minute curvature is determined. The principals of the manufactured Automatic cyclic bending tester by Ajeli et al (Ajeli et al., 2009) is followed by the work of Liversey et al (Livesey, R., & Owen, 1964). The specimen is held at one end in a rotatable clamp, which rotates with DC motor and the angle (α) is determined by a shaft encoder system. The other end of the specimen is attached to an arm system. The position of the arm (β) (Figure 2 (a)) is detected with a rotatable laser sensor (see Figure 2 (b)).

Knowing that the curvature is proportional to the angle α-β and the moment is proportional to sin β. The effective specimen length between the clamps is 0.5 cm and the specimen width is 2.5 cm. For both Shirley tester and automatic cyclic bending tester, four specimens of each sample were tested on average.

Figure 3 demonstrates a typical moment couples - curvature graph of automatic cyclic bending tester. To analyze the experimental results, the slopes of the curve at linear regions (at curvature of ±1 to ±3) have anticipated. The equations (2-4) are utilized to analyze the value of bending rigidity of the samples.

$$M = L.w.\sin\theta \quad (2)$$

$$K = (\beta - \theta)L_{AB} = 2\alpha \quad (3)$$

$$M = BK \quad (4)$$

Where B, M and K are bending rigidity, moment couples and curvature respectively. As can be seen in Figure 3 by corresponding the equation (y=ax+b) with the equation (4) the slope the graph would be the desired bending rigidity.

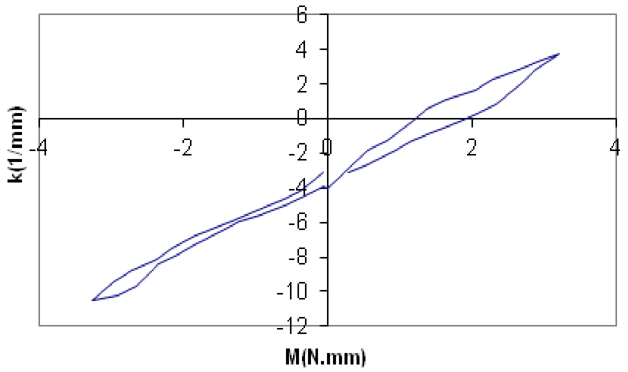


Figure 3. A typical diagram of moment couples- curvature for samples

2.4. Sample Preparation for Cross Section Observation

For observing the cross section of fabric structures, we separated their samples into warp and weft directions and set of five samples such as plain through to Twill 1/5 in a cylinder frames are given in Figure 4. Thereafter a combination of polymeric resins such as Acryl, polyvinyl acetate and nitro cellulose injected into provided white cylindrical frames to fix the samples in the mold. After desiccating the embedded samples in resins, they were polished by series of particular abrasives (dense of 80, 100, 120, 400, 600, 1200, 1500 and 2000). Subsequently, fixed samples grinded by a polisher instrument. Ultimately, the fabric cross-section images achieved clearly under a reflective microscope.

Figure 4. Process of preparing of samples for taking microscopic images

3. Results and Discussion

The experimental data concern to values of bending rigidity of woven fabrics will found at the Table 1. As results show, float length has efficiency on bending rigidity of the woven fabrics. Increasing of float's length infer to decline of bending rigidity's value on both warp and weft directions. The Values of bending rigidity on weft direction for fabrics with density of 23 $\frac{\text{Ends}}{\text{cm}}$ are more than warp direction. Otherwise in the case of samples of 29 $\frac{\text{Ends}}{\text{cm}}$ and 35 $\frac{\text{Ends}}{\text{cm}}$, the mentioned trend would be reversed. Also the Bending rigidity values on technical back side of fabric are more than technical front side in all cases. In experimental analysis as it obvious, in the case of weft density of 23$\frac{\text{Ends}}{\text{cm}}$ the bending rigidity values in weft direction is more than those in warp direction concerning to both sides. Otherwise this trend is reciprocal for 29 $\frac{\text{Ends}}{\text{cm}}$, 35$\frac{\text{Ends}}{\text{cm}}$.

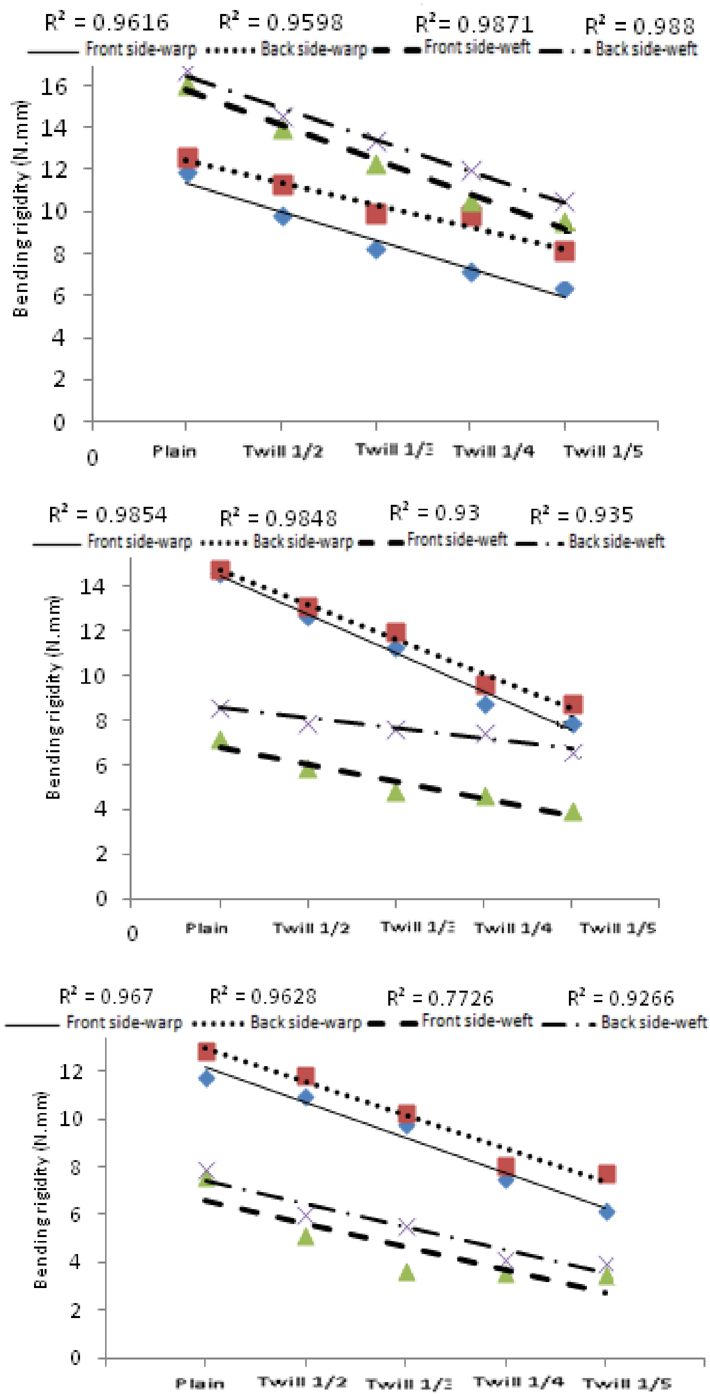


Figure 5. a) Effect of rise of float length on bending rigidity for 23Ends/cm of Weft yarn b) Effect of rise of float length on bending rigidity for 29Ends/cm of Weft yarn c) Effect of rise of float length on bending rigidity for 35Ends/cm of Weft yarn (Shirley tester)

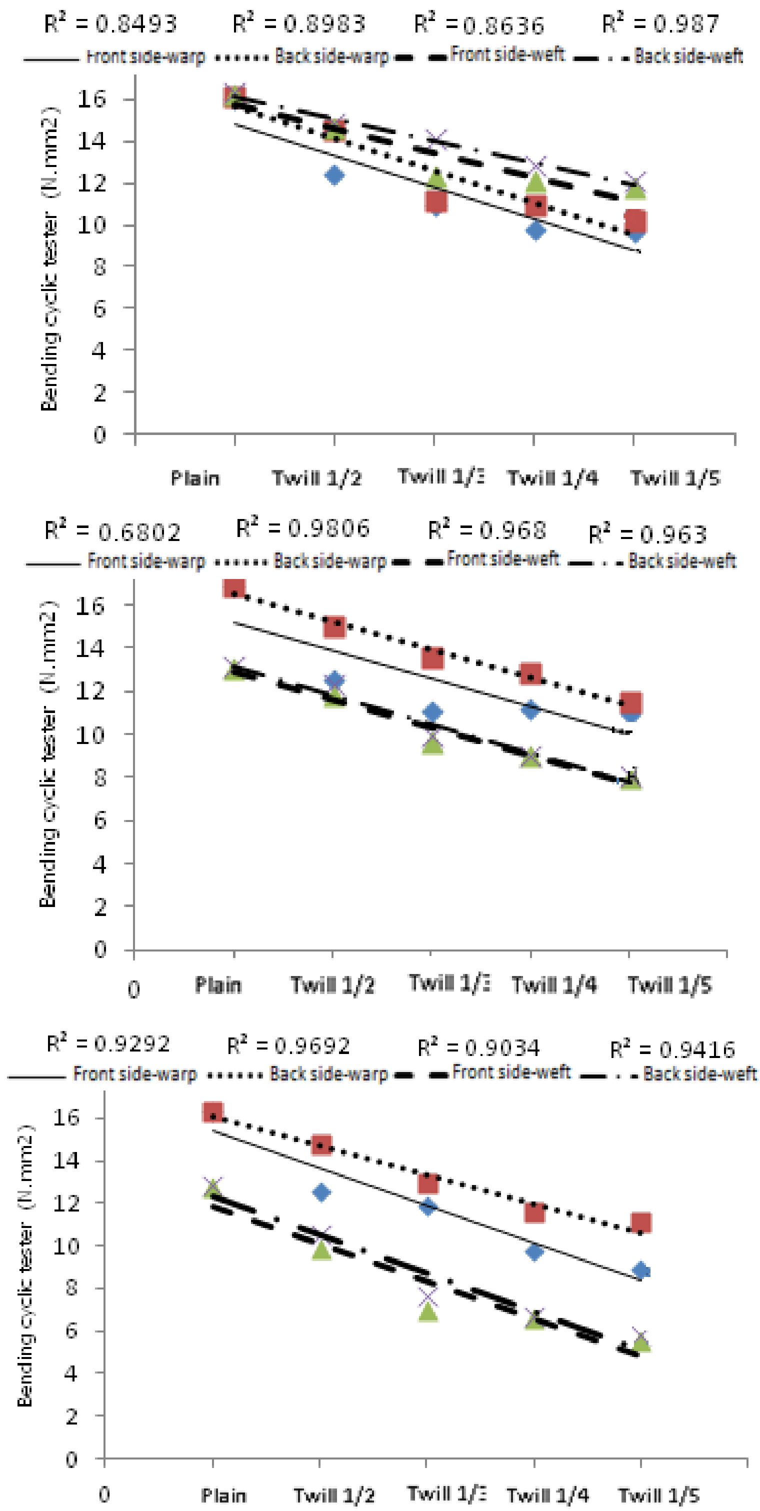


Figure 6. a) Effect of rise of float length on bending rigidity for 23Ends/cm of Weft yarn b). Effect of rise of float length on bending rigidity for 29Ends/cm of Weft yarn c) Effect of rise of float length on bending rigidity for 35 Ends/cm of Weft yarn (automatic Bending cyclic tester)

Here is all statistical data concern to values of bending rigidity via Automatic cyclic bending tester. It can be possible to accessible all detail regard to achieving the means of bending rigidity values in Table 1.

Figure 7 illustrates the microscopic images of cross-sections of warp and weft yarns in fabric structure. As can be seen by increasing the float yarn whit altering on fabric design the configuration of the yarns cross section transform from circular to elliptical shape. This achieved reasoning was validated by the obtained aspect ratio data by means of image processing the cross section warp and weft yarns (MATLAB software).

Table 1. Comparison between values of bending rigidity for both Bending cyclic tester and Shirley tester

$23\frac{Ends}{cm}\frac{Ends}{cm}$	Bending cyclic tester (N.mm2)				Shirley tester (N.mm)			
	Warp direction		Weft direction		Warp direction		Weft direction	
	Front side	**Back side**	**Front side**	**Back side**	**Front side**	**Back side**	**Front side**	**Back side**
Plain	16.00	16.09	16.26	16.34	11.87	12.57	16.06	16.76
Twill $\frac{1}{2}$	12.41	14.52	14.61	14.86	9.78	11.31	13.97	14.53
Twill $\frac{1}{3}$	10.92	11.20	12.27	14.14	8.24	9.92	12.29	13.41
Twill $\frac{1}{4}$	9.84	10.97	12.08	12.81	7.12	9.78	10.48	12.01
Twill $\frac{1}{5}$	9.72	10.16	11.78	12.06	6.42	8.1	9.5	10.48
$29\frac{Ends}{cm}\frac{Ends}{cm}$	**Front side**	**Back side**	**Front side**	**Back side**	**Front side**	**Back side**	**Front side**	**Back side**
Plain	16.83	16.87	13.00	13.15	14.61	14.76	7.16	8.62
Twill $\frac{1}{2}$	12.54	15.03	12.33	11.83	12.71	13.15	5.84	7.89
Twill $\frac{1}{3}$	11.09	13.58	9.65	9.90	11.25	11.98	4.82	7.6
Twill $\frac{1}{4}$	11.23	12.80	9.00	9.02	8.77	9.64	4.67	7.45
Twill $\frac{1}{5}$	11.03	11.50	7.96	8.09	7.89	8.77	3.94	6.57
$35\frac{Ends}{cm}$	**Front side**	**Back side**	**Front side**	**Back side**	**Front side**	**Back side**	**Front side**	**Back side**
Plain	16.30	16.34	12.73	12.85	11.7	12.87	7.55	7.87
Twill $\frac{1}{2}$	12.56	14.75	9.90	10.51	10.97	11.84	5.11	5.99
Twill $\frac{1}{3}$	11.92	12.99	6.93	7.62	9.8	10.23	3.65	5.55
Twill $\frac{1}{4}$	9.81	11.58	6.65	6.59	7.46	8.04	3.57	4.09
Twill $\frac{1}{5}$	8.89	11.10	5.56	5.79	6.14	7.75	3.47	3.94

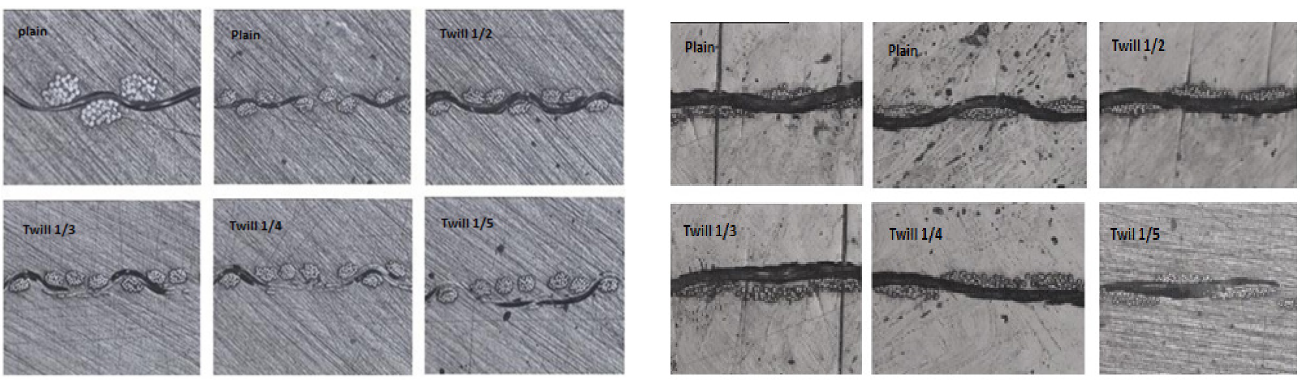
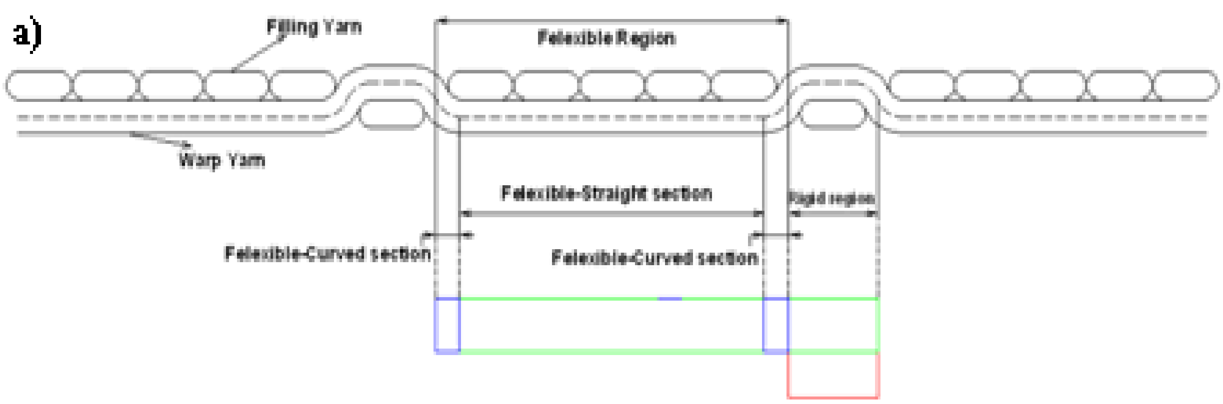


Figure 7. a) Cross section of warp yarns on woven fabric's structure b) Cross section of weft yarns on woven fabric's structure



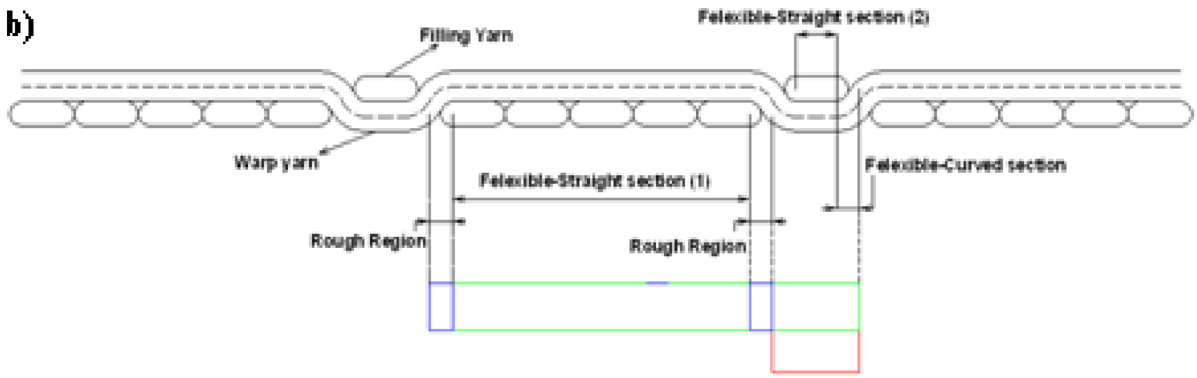


Figure 8. a) Districting sections on simple model for twill 1/5 (Back side) b) Districting sections on simple model for twill 1/5 (Front side)

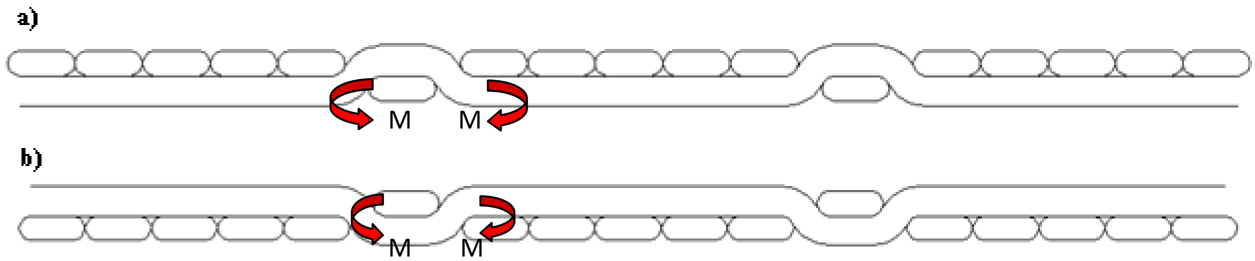


Figure 9. a) Indicating imposed couples on intersection area for twill 1/5 (technical Back side) b) Indicating imposed couples on intersection area for twill 1/5 (technical Front side)

According to the elliptical configuration of the yarns cross section in fabric structure, the determined hypothesizes followed as yarns in which have been weaved in fabrics, are consist of two sections: Rigid region which the area of intersection part and Flexible region that represent the length of area (see Figure 8). This area consists of two separated parts were called straight and curved sections. Here are the examples (Twill 1/5) would be influential in perceiving the consequences of considering the regions.

By assumption of imposing the moment couples showed by means of highlighted red arrows in Figure 9(a). in the case of technical back side as soon as fabrics starts to being bended on certain direction. The couple will cover more length of warp yarn on the surface of weft yarn in intersection area, which treats as a stand point. Consequently, the friction between them will increase which is translated more forces are required to overcome created friction and is followed by increasing of ultimately bending rigidity.

Figure 9(b) shows that, inversely, the mentioned couples will decrease contact length of warp and weft yarns in intersection area. Therefore, the yarns bending rigidity is reduced. For the proof of above outcome's concern to how would be the bending rigidity of the fabrics in both sides, the fabric parameters are needed to take into account. According to the comparison of this assumption, achieved values of bending rigidity and the images of cross section of yarns, it could be inferred that floated yarn and fabric designs accompanied by the yarns parameters have main influences on altering the bending rigidity of fabrics.

There would be exploited main outcomes in the case of increasing of the bending rigidity based on growing float yarns. According to the shape of yarns cross section (Figure 7), particularly in plain fabrics, the filaments based on the imposed forces with the respect to fabric structure, conflicted together which is due to high friction forces between entangled filaments. Hence the friction forces between the filaments are caused to transforming the fabric structure to a rigid form. Otherwise, by increasing the float yarns in fabric structure, the amount of mentioned friction forces are declined that could be translated to higher flexibility and as a result the amount of bending rigidity will decrease.

As matter of fact, the future work would be considered to figure out the theoretical mechanical relation between these denoted parameters and assumptions with their affects on Bending rigidly of fabrics. Also comparing these approaches with gained experimental data would be inevitable.

4. Conclusions

In this study, the relationship between the bending rigidity of woven fabrics discussed. Moreover, we demonstrated that the results from the Shirley tester and automatic cyclic bending apparatus correlated well together. As results show, float length has efficiency on bending rigidity. Increasing of float's length infer to decline of bending rigidity's value on both warp and weft directions. The Values of bending rigidity on back/front side of fabric in weft direction for fabrics with density of 23 $\frac{\text{Ends}}{\text{cm}}$ are more than warp direction. Otherwise about samples of 29 $\frac{\text{Ends}}{\text{cm}}$ and 35 $\frac{\text{Ends}}{\text{cm}}$, the mentioned trend would be reversed. Also the Bending rigidity values on technical back side of fabric is more than front side of fabrics in all cases which meaningful explanations were considered. There is difference between bending rigidity in weft and warp direction. Eventually a reasonable agreement between the measured values for both techniques is inevitable.

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REFERENCES

[1] Abbott, G.M., Gorsberg, P., & Leaf, G. A. . (1971). The mechanical properties of woven fabrics, Part VII: The hysteresis during bending of woven fabrics. Textile Research Journal, 41(4), 13.

[2] Abbott, G.M., Gorsberg, P., & Leaf, G. A. V. (1973). The elastic resistance to bending of plain-woven fabrics. Journal of Textile Institute, 64(6), 24.

[3] Abbott, N., Coplan, M., & Platt, M. (1960). Theoretical Considerations Of Bending And Creasing In A Fabric. Journal of the Textile Institute Transactions, 51(12), 13.

[4] Ajeli, S., Jeddi, A. A. A., Rastgo, A., & Gorga, R. E. (2009). An analysis of the bending rigidity of warp-knitted fabrics: a comparison of experimental results to a mechanical model. The Journal of The Textile Institute, 100(6), 496–506.

[5] Allaoui, S., Hivet, G., Wendling, A., Soulat, D., & Chatel, S. (2011). Experimental approach for optimizing dry fabric formability. arXiv preprint arXiv:1110.5179.

[6] Ancutienė, K., Strazdienė, E., & Nesterova, A. (2010). The relationship between fabrics bending rigidity parameters defined by KES-F and FAST equipment. Materials Science= Medžiagotyra, 16(4), 346–352.

[7] Dehkordi, M. T., Nosraty, H., Shokrieh, M. M.,Minak, G., & Ghelli, D. (2010). Low velocity impact properties of intra-ply hybrid composites based on basalt and nylon woven fabrics. Materials & Design, 31(8), 3835–3844.

[8] Fatahi, I., & Yazdi, A. A. (2010). Assessment of the relationship between air permeability of woven fabrics and its mechanical properties. surfaces, 5, 6.

[9] Grosberg, P. (1966). The Mechanical Properties of Woven Fabric - Part II: The Bending of Woven Fabrics. Textile Research Journal, 36, 6.

[10] Grosberg, P., & A. G. . (1966). Measurement of Fabric Stiffness and Hysteresis in Bending. Textile Research Journal, 36, 6.

[11] Grosberg, P., & Swani, N. . (1966). The Mechanical Properties of Woven Fabric - Part IV: The Determination of the Bending Rigidity and Frictional Restraint in Woven Fabrics. Textile Research Journal, 36, 7.

[12] Kedia., G. and. (1966). The Mechanical Properties of Woven Fabrics: Part I: The Initial Load Extension Modulus of Woven Fabrics. Textile Research Journal, 36(8).

[13] Leaf, G.A., Chen, Y., & Chen, X. (1993). The initial bending behavior of plain-woven fabrics. journal of Textile Institute, 84(4), 9.

[14] Livesey, R., & Owen, J. (1964). Cloth Stiffness and Hysteresis in Bending. Journal of the Textile Institute, 55(10), 14.

[15] Luible, C., & Magnenat-Thalmann, N. (2007). Suitability of Standard Fabric Characterisation Experiments for the Use in Virtual Simulations. In Proceedings of World Textile Conference AUTEX 2007 (pp. 1–5).

[16] Merati, A., & Patir, H. (2011). Anisotropy in wrinkle properties of woven fabric. The Journal of The Textile Institute, 102(7), 639–646.

[17] Peirce, F. (1930). The handle of cloth as a measurable quantity. Journal of the Textile Institute, 21(9), 39.

[18] Sun, D., & Stylios, G. K. (2012). Cotton fabric mechanical properties affected by post-finishing processes. Fibers and Polymers, 13(8), 1050–1057.

[19] Syerko, E., Comas-Cardona, S., & Binetruy, C. (2012). Experimental Characterization and Modeling of Bending Properties of Woven Fibrous Preforms. Key Engineering Materials, 504, 277–282.